CHAPTER II

Nuclear Radioactivity and Radiobiology

2.1 Introduction:

Radioactive elements, discovered a long time ago, their applications in the nuclear field have only been recently used. In the year 1895, Roentgen discovered a type of rays that blacken a photographic plate and produce ionization in any gas through which it passes. Not knowing how to characterize them, he called them X-rays. A year later, in 1896, Becquerel discovered that crystals of Uranium salts emitted rays, similar to X-rays in that their high penetration of solids, effect on photographic plates, and inducing of electrical conductivity in gases.

Later in the year 1898, the Curies identified two radioactive elements Plonium and Radium.

X-rays, defined later as highly energetic photons, are released from excited atoms during electronic transitions between the innermost orbits. However, spontaneous radioactivity is a property of the atomic nucleus i.e. it is a highly energetic beam of particles ejected from unstable nuclei.

2.2 Radiation Spectrum:

The nucleus consists of positively charged protons and uncharged neutrons held together by very strong nuclear forces set up by the exchange of elementary particles, called ***mesons,*** among the neutrons and protons. In radioactive nuclei, the forces between nucleons are unable to overcome the repulsion forces between the protons leading to the instability of the nucleus. Thus, it becomes necessary for the nucleus to emit the excess energy, in the form of ionizing radiations, to reach a more stable condition.

Radioactive nuclei can be either natural or artificial. The first three radiations emitted from uranium are α, β and γ radiations. Their properties are summarized in the following table:

Radiation	**Charge**	**Mass**	**Properties**	**Velocity**
α- particles	+ve charge 2 protons + 2 neutrons	Mass of Helium	Deflected by E&H fields	} 1/10 C
β-particles	-ve or +ve charge (electrons or positrons)	Mass of electron	Deflected by E& H fields	
X & γ	photons (uncharged)	Mass-less	No deflection	$C=3\times10^8$m/s

Radiation	Ionization	Energy Range	Range in tissue	Decay pathway
α	10,000ion/sec	1-20Mev	1-10 μm	${}^{A}_{z}X \rightarrow {}^{A-4}_{z-2}y + {}^{4}_{2}He$
β	100 ion/sec	10Kev-15Mev	10 μm-0.05m	${}^{A}_{z}X \rightarrow {}^{A}_{z+1}y + {}^{0}_{-1}e + \nu$ *or* ${}^{A}_{z}X \rightarrow {}^{A}_{z-1}y + {}^{0}_{+1}e + \nu$
X & γ	1 ion/sec	10Kev-2Mev	10^{-3}-10^{-1} m	${}^{A}_{z}X \rightarrow {}^{A}_{z}X + \gamma$

Table 2.1 Comparison of the three well-known types of radiation

The three radioactive rays, mentioned in Table (2.1), emitted from radioactive materials show different paths under the effect of a normal magnetic field to the plane of the emission as shown in fig. (2.1).

There are two methods to identify the different types of radiation:

i. The measurement of absorption of ionizing radiation rays by their penetration through various thicknesses of solids and gases.

ii. The measurement of the extent to which they are deflected by magnetic and electric fields, recorded on the photographic plate, as shown in fig (2.1).

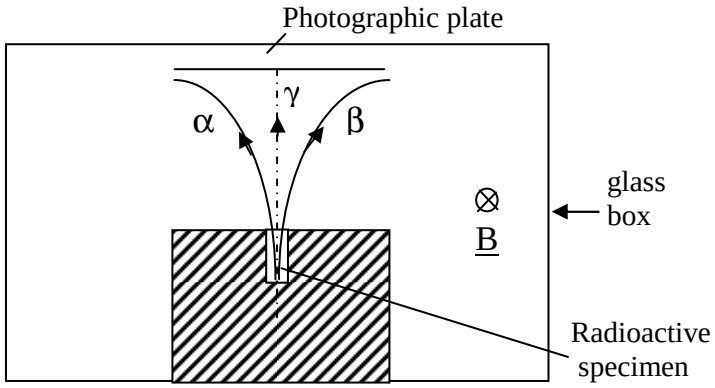

Fig. 2.1
Normal magnetic field is incident on the plane of the emission

2.3 Transformation in Radioactive Decay:

When radioactive decay or disintegration takes place, transformation of a substance to another takes the form: $X^* \rightarrow X + x$

X* is known as the parent nucleus, X is known as the daughter nucleus, and x is the ejected particle.

Examples:

1. $^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\alpha$ ... (1620 yrs) (2.1)

Radium is considered the parent nucleus and Radon is the daughter nucleus which is less in mass number, A, by 4 and in atomic number, Z, by 2 such that:

$A = A^* - 4$ $Z = Z^* - 2$ $x = {}^4_2\alpha$ or ${}^4_2He$

The ejected particle must be alpha-particle whose mass number is 4 and charge number is 2.

2. ${}^{231}_{90}Th \rightarrow {}^{231}_{91}Pa + {}^{0}_{-1}\beta$ (25.5 hrs) … (2.2)

Thorium is the parent nucleus where a neutron is transformed into a proton by emitting an electron in the form of beta particles radiation and transforms to Protacium. The nuclear transformation parameters are: $A = A^*$, $Z = Z^* + 1$

$x = \beta^-$, or a beam of electrons.

3. ${}^{25}_{13}Al \rightarrow {}^{25}_{12}Mg + {}^{0}_{+1}\beta$ (3.4 hrs.) … (2.3)

Aluminum is transformed into Magnesium when a proton is transformed to a neutron through emitting a positron. The transformation equation is: $A = A^*$

$Z = Z^* - 1$ $x = \beta^+$, or a beam of positrons. These are the positively charged particles each having a mass as the electrons and charge $+1.6\times10^{-19}$ c (electron twin).

4. ${}^{87}_{38}Sr^* \rightarrow {}^{87}_{38}Sr + \gamma$ (2.8 hrs.) … (2.4)

The Strontium excited nucleus simply emits energy in the form of a gamma rays and doesn't change its integral parameters. A gamma emitting nuclide, known as an isomer of the daughter nuclide, exists for a measurable half-life time. The emitted energy is the difference in energy between the energy of excited isomer and that of the final stable state.

5. ${}^{7}_{4}Be + {}^{0}_{-1}e \rightarrow {}^{7}_{3}Li + \nu$ … (2.5)

Berillium is the parent nucleus and Lithium is the daughter one, which has the same mass number and an atomic number lessened by one. An electron is captured by the Berillium nucleus and this type of nuclear decay is known as electron capture. The neutrino, *v*, particle is an energy particle with no mass or charge. Its release usually accompanies this type of decay.

There are other types of nuclear decay, e.g. neutron or proton emission.

2.4 The Binding Energy:

The binding energy is defined as the stored energy inside the nucleus that holds its components together. Einestien stated that whenever matter loses or gains mass this is accompanied by loss or gain of energy. The mass energy transformation equation is calculated as:

$$\Delta E = \Delta m\, C^2$$

Thus the binding energy, E_b , is calculated as the difference between the sum of the masses of a group of separate nucleons and the mass of the compound nucleus containing these nucleons, when multiplied by square of the light velocity (C^2).

$$E_b = (Z \times m_p + N \times m_n - M_A) \times C^2 \ [J \text{ or } kg.m^2.s^{-2}] \qquad \ldots(2.5)$$

If masses are expressed in atomic mass unit, ***u***, then

$$E_b = (Z \times m_p + N \times m_n - M_A) \times 931.494 \ [MeV]$$

where m_p is the proton mass, m_n is the neutron mass, and M_A is the mass of nucleus (atomic mass).

For higher stability of the nucleus, the binding energy must be greater than total internal repulsion energy between the protons inside the nucleus such that:

$$E_b \rangle \sum_{i,j}^{Z} \frac{q_{ij}^2}{4\pi\varepsilon_0 r_{ij}} \qquad i \neq j \qquad \ldots.(2.6)$$

For radioactive nuclei this condition is not adequately satisfied and thus is said to be unstable and releases energy in the form of a beam of fast particles. Fig.(2.2) shows the stability curve for materials. The vertical axis represents the binding energy per nucleon, i.e. E_b/A in eV. The most stable has the highest binding energy, shown around the peak of the curve. It is worth noting that these nuclei have even mass numbers.

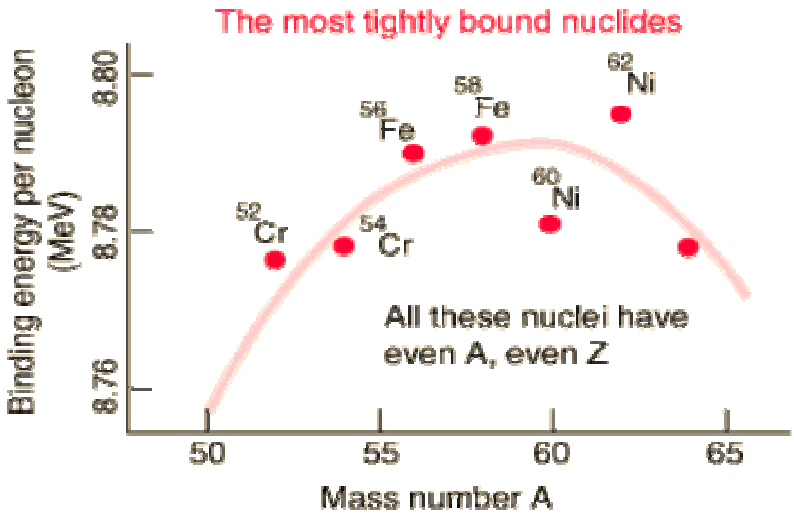

Fig. 2.2
The stability curve for materials, the peak of the curve is the iron isotopes

2.5 The Disintegration Energy:

It is the relativistic energy accompanied by each nuclear decay or disintegration. If M_x is the mass of the parent nucleus, M_y is the mass of the daughter nucleus and M_z is the mass of the released particle, then the quantization energy, Q is defined as:

$$Q = (M_x - M_y - M_z) \times c^2 \ [J] \qquad \ldots(2.7)$$

If masses are expressed in atomic mass unit(u) then

$$Q = (M_x - M_y - M_z) \times 931.494 \ [MeV] \qquad \ldots(2.8)$$

If Q is positive, then the decay can occur spontaneously and energy is released as a result. Whereas if Q is negative, it means that the decay is non-spontaneous. It consumes energy to take place.

Drill1: Calculate Q for each one of the transformation equations (2.1-2.2-2.3-2.5). Note that for eq.(2.4) you can't deduce the released energy using eq.(2.4) as the ejected particles in this case are mass-less photons. The released energy is calculated as $h\upsilon$, where h is Planck's constant and υ is the radiation frequency.

There are three main series of spontaneous decays occurring naturally, natural decay series, (*see ref.* *). Each series starts with an isotope whose $T_{1/2}$ exceeds that of any of its descendants (daughter nuclei). The three series end in the most stable element on earth, lead $^{206}_{82}Pb$. One of these series is shown in fig.2.3.

2.6 The Nuclear Reactions:

It is possible to change the structure of nuclei by bombarding them with energetic particles. The nuclear equation means that the nucleus X is bombarded with particles, a, to produce another nucleus Y and excess energy is released as particle beam, b. The produced energy could be of very useful applications, (*see ref.**)

$$X + a \rightarrow Y + b$$

The disintegration energy can hence be calculated as:

$$Q = (M_x + M_a - M_y - M_b) \times c^2 \ [J] \qquad \ldots(2.9)$$

If masses are expressed in atomic mass units (u) then

$$Q = (M_x + M_a - M_y - M_b) \times 931.494 \ [MeV] \qquad \ldots(2.10)$$

** Ref. : chapters 44,45,46 of Serway & Biechner*

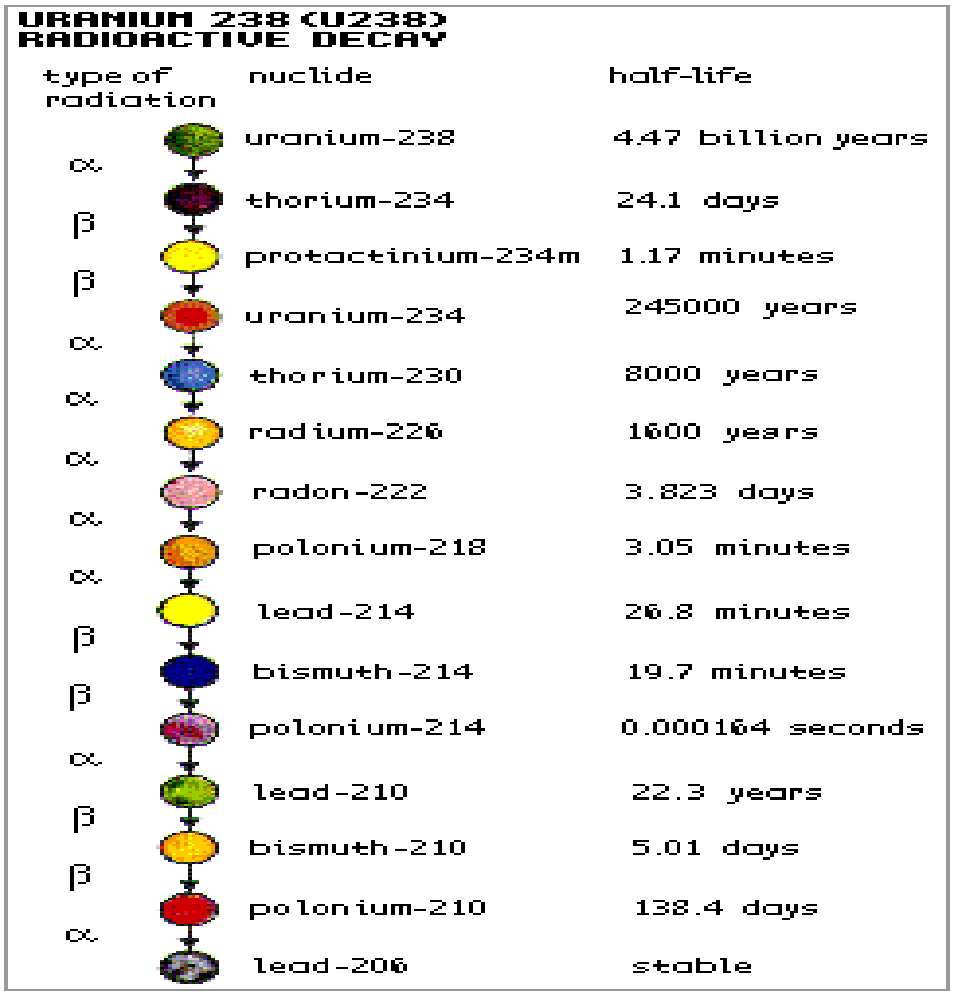

Fig. 2.3
The natural radioactive series, starting with uranium and ending with lead

2.7 The Radioactive decay law:

The rate of decay is related to the number of nuclides, shown in fig.(2.4), mathematically as:

$$\frac{dN}{dt} = -\lambda N \qquad \ldots(2.11)$$

where λ is the decay constant measured in sec^{-1} and represents the fractional rate of disintegration. N is the number of nuclei present at any arbitrary instant, t.

$$\therefore \frac{dN}{N} = -\lambda dt$$

By integration from N_0 to N, $\therefore \ln(N/N_0) = -\lambda t$

$$N = N_o \; e^{-\lambda t} \qquad \ldots (2.12)$$

where N_o is the number of nuclei at an initial instant, t=0.

The rate at which the nuclear species decay, is characterized by a time constant known as the half-life time, τ. It is defined as the time required so that the number of the parent nuclides will decay to half its original value. τ is a property of the nucleus and is independent of any chemical or physical state of the atom.

At time $t = \tau \rightarrow \boldsymbol{N = N_o/2}$

$$\therefore \boldsymbol{N_o/2 = N_o\ e^{-\lambda\tau}}\ ,\ \therefore\ \tau = \frac{\ln 2}{\lambda} = \frac{0.6931}{\lambda} \qquad \ldots (2.13)$$

Example 2.1:

The isotope carbon-14 $^{14}_{6}C$, is radioactive and has a half-life of 5730 years. If you start with a sample of 1000 carbon-14 nuclei, how many nuclei will still be around in 22920 years?

Solution:

In 5730 yrs. the original number of nuclei is reduced to half its value, 500.

After another 5730 yrs., i.e. 11460 yrs., the no. of nuclei will become 250.

Then the no, will be 125 after 17190 yrs.

Eventually, after ***22920*** yrs. the number will be ***62*** nuclei.

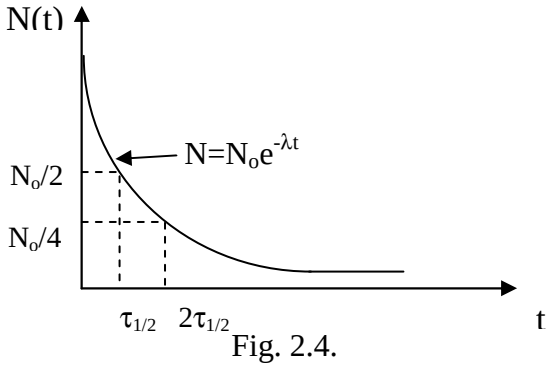

Fig. 2.4.

2.8 Decay Processes:

2.8.1 Activity:

The activity of the specimen, I, is defined as the number of disintegrations per unit time.

$$I = \left|\frac{dN}{dt}\right| = \lambda N \qquad \ldots(2.14)$$

The units, used to measuring the activity of a radioactive specimen, is the Curie (C_i) or the Becquerel (B_q).

$1\ C_i \equiv 3.7\times 10^{10}$ decays/s (activity of 1g of Radium)

$1\ B_q \equiv 1$ decay/s

For a single activity:

$$I = \lambda N_o e^{-\lambda t} = I_o e^{-\lambda t} \qquad \ldots(2.15)$$

Taking natural logarithm of both sides;

$$\ln I = \ln I_o - \lambda t \qquad \ldots(2.16)$$

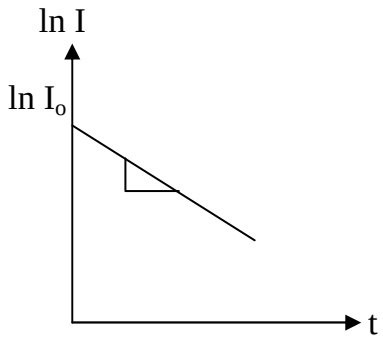

Fig. 2.5.

Accordingly, the slope of the plot of the logarithm of the counting rate against time, shown in fig.(2.5), gives the decay-constant, λ. The evaluation of λ is independent of the initial instant chosen, t=0.

2.8.2 Radiation Intensity:

The radiation power, R(irradiance), is measured as the product of the disintegration energy, Q, by the activity, I. Moreover the total energy received is the product of number of nuclides, N, by the disintegration energy, Q.

$$\boldsymbol{R(t)= Q\times I(t) = Q\,\lambda\, N_o}\, e^{-\lambda t} \qquad \boldsymbol{MeV/s} \qquad \ldots. (2.17)$$

$$\boldsymbol{E(t)= Q\times N(t)= Q\, N_o}\, e^{-\lambda t} \qquad \boldsymbol{MeV} \qquad \ldots. (2.18)$$

2.9. Radioactive absorption:

There are some elements that have more ability to absorb radioactive radiation than others. These materials are useful for making shields and boxes to embed the radioactive specimen and thus reduce their harmful effects on people. The degree of radiation absorption is measured by, μ, known as the linear absorption coefficient. The radiation power, ***R***, is related to μ by:

$$\boldsymbol{R(t)= R_o\, e^{-\mu x}} \qquad \ldots. (2.19)$$

where R is the radiation intensity after passing through the shielding of thickness x and R_o is that initially radiated, without shielding.

Taking ln both sides of equation (2.19)

$$ln\ R = ln\ R_o - \mu x \qquad \ldots. (2.20)$$

The linear absorption coefficient, μ, can be easily deduced from a graph representing ln the radiation intensity against the shielding material thickness. The half value thickness, $X_{1/2}$ corresponds the value where the intensity, R, falls to half its original value at x = 0

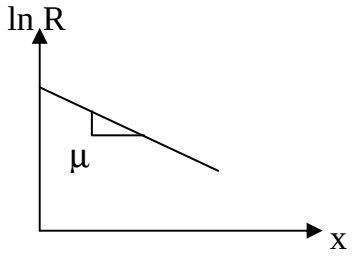

Fig. 2.6

$$X_{1/2} = \frac{\ln 2}{\mu} = \frac{0.6931}{\mu} \qquad \ldots.(2.21)$$

2.9 Detectors of Nuclear Radiation:

2.9.1. Ionization Chamber:

It essentially consists of a gaseous chamber that contains two electrodes connected to a high voltage power supply, shown in fig.(2.7). Charged or ionizing particles passing through the gas, leaving in its wake a large number of ion pairs. An ion pair consists of an electron and a positively charged molecule. Electrons produced by ionization are attracted towards the anode while +ve ions are accelerated towards the cathode. The rate at which the electron-ion pairs are produced, known as the ionization rate, ***n***, is proportional to number of electrons that travel through the wire per second.

The potential difference between the electrodes, *V*, is varied and the current, *I*, is measured using the μammeter, the current-voltage characteristic, shown in fig.(2.8). In the low voltage region the electrons produced in the chamber achieve relatively low

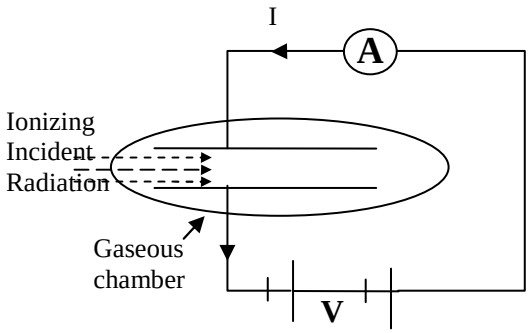

Fig.2.7
Ionization chamber

velocities so the current is low. Consequently, many positive ions and electrons recombine to form neutral atoms before they reach the electrodes. As *V* increases, the rate of recombination is reduced.

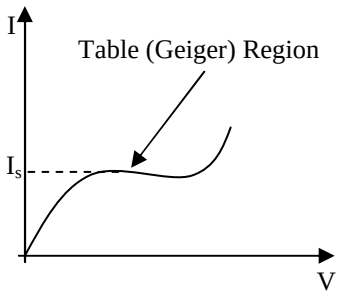

Fig.2.8
V-I characteristic

The horizontal part of the curve, known as the Geiger region, indicates that all of the electron-ion pairs formed reach their respective electrodes contributing to the outer current in the circuit. The current in this region remains constant, no matter how voltage increases, and is equal to the total charge produced by ionization per second ($\boldsymbol{I_s=ne}$). It is known as the saturation current, and is a measure of the energy produced by the ionizing radiation per second. These currents are so small that they are undetectable by known methods.

Example 2.2:

A 2Mev α-particle radiation produces about 60,000 ion pairs/s. What is the reading of the ammeter?

Solution: The particles cause a charge transfer of 60,000 ionic pairs between the diodes. Hence the total charge, Q = $60{,}000\times1.6\times10^{-19}$coulomb. So every second approximately a 10^{-14} coulomb charge is dissipated in the circuit and the current value is 10^{-14} A. → $I=0.96*10^{-14}$ A .

Thus, it is impossible to measure such small currents with milli or micro ammeters. Electronic amplifiers are used to detect the pulse of the current resulting from the passage of a single charged particle through the chamber. The pulse of the current due to each charged particle has a magnitude proportional to the particle energy. Therefore the number of particles per second can thus be estimated by counting the current pulses.

2.9.2. Geiger-Muller Counter:

The concept of amplifying the charge transferred to the electric circuit is the main issue. If the electrons, produced by ionization, are accelerated to high velocities, they themselves produce further ions by collision. This process which is known as "*gas amplification*", results in a much greater current than that produced by the original ion pairs. Fig (2.9) shows the main illustration of the Geiger Muller tube where the central wire stands as the anode and the surrounding copper cylinder for the cathode. A high radial electric field, initiated between the axial wire and the outer cylinder, apply an electrostatic force on the electrons causing them to be highly accelerated towards the anode with an electrostatic force, $\boldsymbol{F_e}$, ($\boldsymbol{F_e = e\, dV/dr}$). Electrons, once generated by collision, are accelerated towards the axial anode, producing more electrons by more collisions. These electrons in turn reproduce more and more ion pairs. This process is known as "***avalanche***". Counter circuits, taking the output current pulses as input, should operate in the Geiger region or table region, where the current is independent of the increase in voltage.

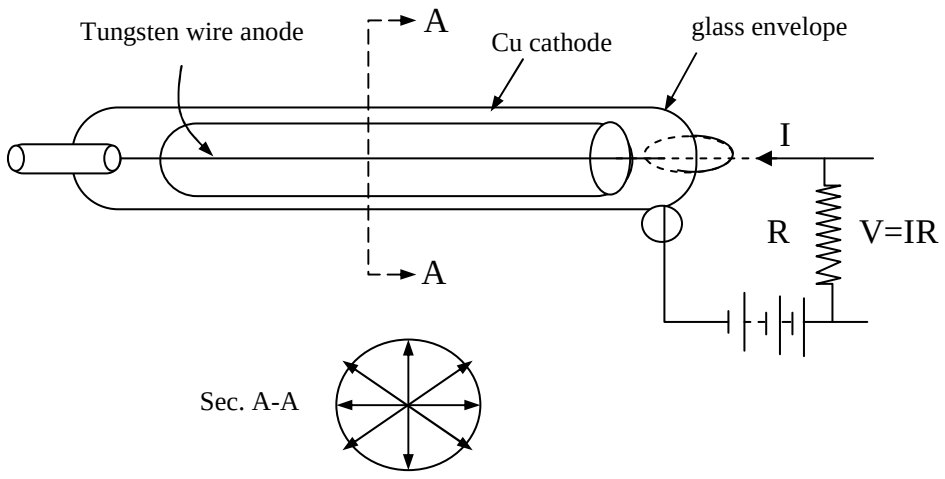

Fig. 2.9. Geiger Counter tube& sec A-A shown the radial electric field

2.9.3. Scintillation Counter:

The α-particles were detected in the past by the light flashes or scintillations produced when they struck certain materials such as zinc sulfide. The scintillation counter was then introduced to give a measure of them. It is shown in fig.(2.10) and it consists of: i. Scintillation material or phosphor which produces a tiny light flash when a charged particle passes through it.
ii. The photo-multiplier tube which detects the light flash and produces an electrical impulse. iii. Amplifiers and electronic circuits which record and count the electrical impulses from the photo-multiplier tube.

The passage of a charged particle through the scintillating material causes some of the scintillation atoms to become excited. As the electrons inside these excited atoms return to their ground states, photons one emitted. The number of photons and hence the intensity of light flash, depend on the energy lost by the charged particle traversing the phosphor.

The most suitable scintillation phosphors chosen to suit various applications are: Cesium Iodide crystal, adding a small activating quantity of thallium, used to detect protons and α-particles or Sodium Iodide, activated with thallium, used for the detection of γ rays.

Steps of the scintillation counter operation:

i. The photons, emitted from the excited atoms of the scintillator, strike the photo-cathode in the photo-multiplier tube causing photoelectric emission. About 10% of the incident photons produce photoelectrons.
ii. Photoelectrons produced inside the tube are then accelerated towards the first dynode, D_1, which is held positive. D_1 has a specially prepared surface such that on being hit by the electrons more electrons are ejected from it. The potential

difference between the photo-cathode and D_1 is held to a value such that each electron causes a secondary emission of four electrons from its surface.

iii. The velocity of the secondary emitted electrons from D_1 is nearly zero. They are then accelerated towards the second dynode D_2, where secondary emission again occurs. Now the four electrons, initially produced by a single photoelectron, become sixteen and so on. The practical photo multiplier tube consists of 10 or 11 dynodes.

iv. A detectable current pulse passes through the last dynode, usually called the collector of the photo-multiplier.

This current is equal to the number of incident electrons per second multiplied by 4^n, where n is the number of dynodes.

2.10 Biological Effects of Radiation:

The radio-sensitivity differs according to the type of the cell. The most radio-sensitive cells are those which have highest division rate, retain the capacity of division, and the least differentiated.

The main effects of radiation on the living cells:

i)The energy available in the irradiated particles is transferred to the molecules causing them to eject electrons. If these electrons take part in ionic bonds, then the molecules would break up into their constituents. If molecules are not broken up then their structure may be altered which necessarily alters the functions of these molecules, especially enzymes.

ii) The irradiation of water gives rise to products which react with the biological materials that contain a high percentage of water. The water molecule is split up either into H^+ and OH^- ions or into the neutral H and OH groups known as free radicals.

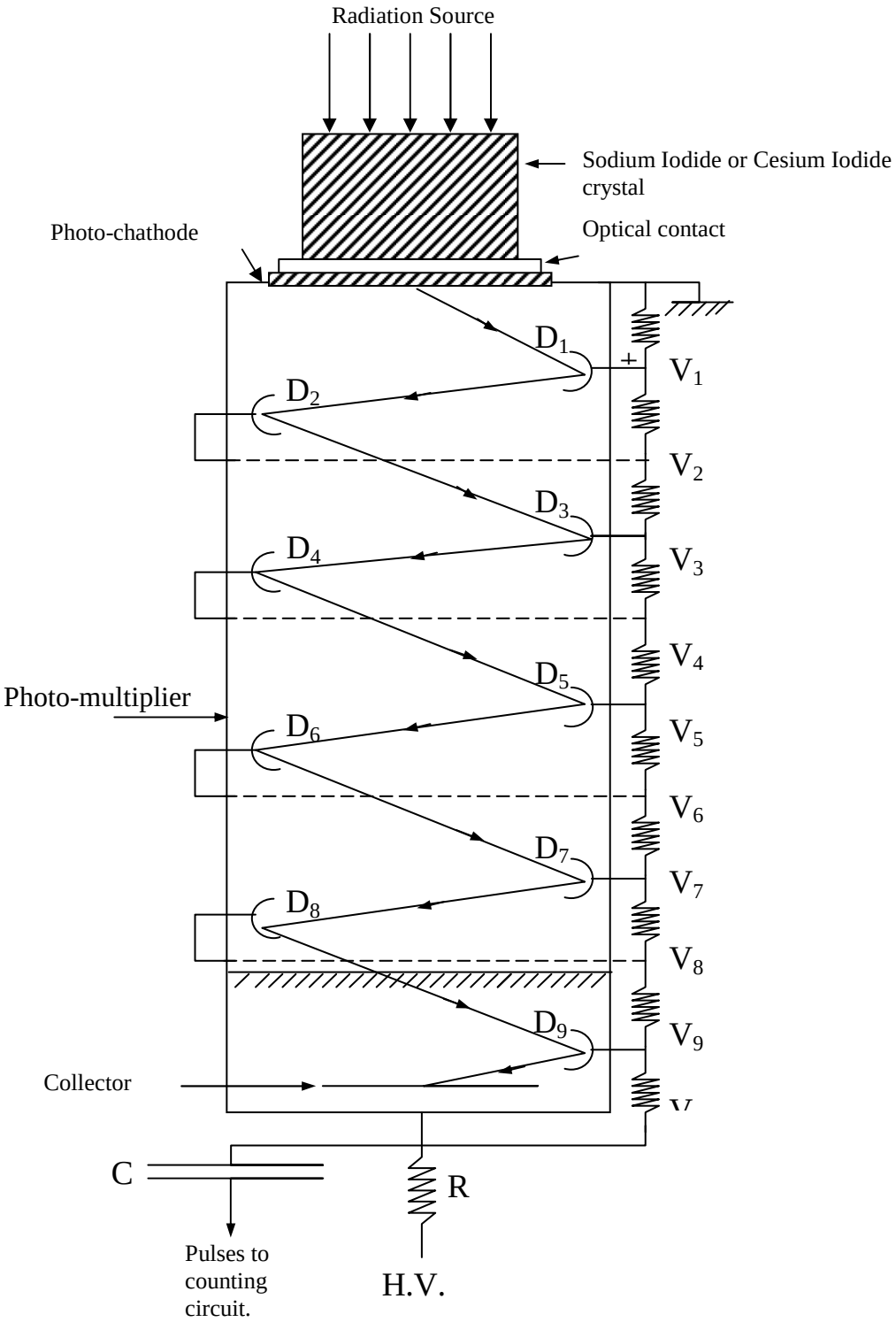

Fig.2.10 Schematic diagram of a crystal Scintillation counter of ten dynodes

These are very reactive chemically OH is a powerful "oxidizing agent", attracting electrons to form OH ion thus breaking chemical bonds.

These ionizing effects of radiation can cause disturbance of genes which carry necessary information for the synthesis of new materials. The disturbance occurring is proportional to the total number of ionization i.e. the total dose of radiation irrespective of the time duration.

iii) The radiations induce gross changes in tissues. They produce mutations in the genetic materials of the living cells. The number of radiation-induced mutations increase linearly with the dose as shown in Fig.(2.11). The absorption of α, β, γ or x radiations by a cell cause its damage, death or mutations.

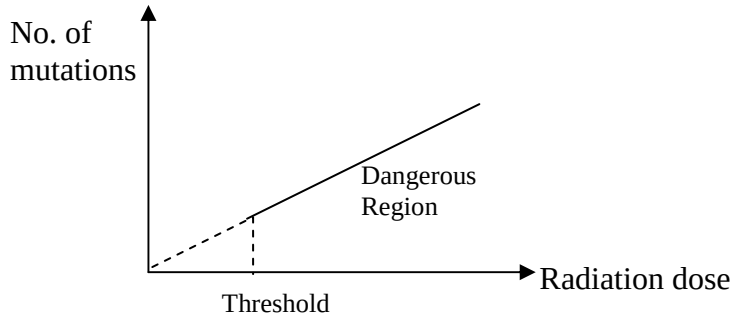

Fig. 2.11.
The increase of number of mutations in the living cell with radiation dose

The lower or minimum level of background radiations from natural sources like cosmic rays, soil or radioactive rocks is suggested by international health institutes to be 0.13 rem/yr for human beings. The *SAFE* limit is within the range of 0.5rem/yr while the *UPPER* limit corresponding to the threshold point oh the mutations curve is around 5rem/yr.

2.11 Radiation Damage in matter:

2.11.1 Radiation Measurement:

It is extremely important to measure the amount of damage done to matter, especially living tissues, as a result of being subjected to radiation. The amount of energy absorbed by one kilogram or gram of the tissue is known as the dose received by this tissue. Besides, the damaging effect of this absorbed energy differs according to the type of the radiation.

The unit of dosage of X-rays is the ***roentgen (R)*** which is defined as the quantity of x-rays that loses 83.4×10^{-7} J/g in air.

Another unit, widely used now, is the ***rad*** which is the dosage of x-rays that produces energy losses of 10^{-5} J/g of absorbing material. This is caused by 250 keV x-ray radiation. The dose that equals 1rad identifies the amount of radiation that causes a transfer of energy of 10^{-2} ***J/kg*** to the absorbing material.

Dosages of other types of radiation produce different effects on living tissues as shown in Table(2.2). These dosages are measured in terms of the rem, defined as the radiation equivalence in man. 1 ***rem*** is equivalent to 1 ***rad*** for x-rays or γ-rays. The ratio of the rem to the rad is called the relative biological effectiveness, ***RBE***.

$$\text{RBE} = \text{rem} / \text{rad} \qquad \ldots(2.23)$$

RBE can also be defined as the number of rems of the radiation being used that produce the same biological damages as that produced by 1 rad of x-radiation or gamma radiation.

Some RBE factors are shown in the following table:

Radiation	RBE factor
x-rays γ-rays	1
β-rays	1-1.7
α-rays	10-20
Heavy ions	20
Fast neutrons or protons	10

Table (2.2)
Effect of different types of radiation on living tissues

It is obvious that as the high RBE values indicate higher damaging effect of the radiation.

Also the linear energy transfer (***LET***) should be defined here. It is the energy deposited per meter of particle path length (J/m). It determines the penetration damage caused by the radiation as well as the energy transferred to the material by it. LET is directly proportional to the square of the particles charge and inversely proportional to the square of its velocity.

2.11.2 Sources of Dangerous Radio-active Materials:

i) The air we breathe contains small quantities of carbon dioxide containing ^{14}C isotope. The food we eat contains traces of ^{40}K & ^{14}C.

ii) Any atomic explosion sends large quantities of radio- active materials into the atmosphere which gradually settle back to the earth in the form of radio-active fallout.

iii) Three principal isotopes represent a danger if ingested through food or drink; ^{131}I, ^{90}Sr and ^{137}Cs.

The danger of each isotope depends on its lifetime $T_{½}$ of ^{131}I is only a few days (8.04days). Its danger is a threat if dairy cattle graze on contaminated grass so their milk will contain the isotope. Its danger is eliminated if their milk is not used for a few weeks. $T_{½}$ of ^{90}Sr is long, 29.1 yrs, so it is very dangerous if it is eaten by animals or taken by plants from the soil. It is ingested by humans from milk, milk products, cereals and vegetables. It is laid down in bones with calcium. Once in bone it persists there producing bone cancer and a plastic anemia, due to destruction of bone marrow. Though $T_{½}$ of ^{137}Cs is longer than that of ^{90}Sr, 30 yrs, and hence persists for longer time in the soil, it is less dangerous. This is so, because it speeds throughout the body and thus does not produce concentrated effects. It is eliminated easier and faster than the other two types. It is acquired from milk and meat.

2.12 Some biological applications of using radio-active materials:-

i) Radio-cardiology is a method of investigating heart and pulmonary conditions. A 10 millimeters tracer element of ^{137}Ba of $T_{½}$ = 127s is injected into the sub-clavian artery. A counter directed from above the heart detects the presence of the tracer. There's a dip as it is pumped out of the lungs and a rise when it returns to the heart. If the heart and lungs are functioning normally the recording obtained will have a typical form. Blockage of blood stream can be located. Diagnosis of various congenital and pathological heart and lung conditions can be rapidly and easily established.

ii) Radio-therapy is simply the killing of the infected cells using radio-active materials. Tubes containing radium and some similar isotopes can be implanted around the offended volume for a calculated time. A dose of ^{131}I is given for the treatment of hyper thyrodism. ^{32}P is used for the treatment of polycythemia. Ra isotopes are used to damage the cancer cells by implanting a calculated mass of few nano grams in tumors.

iii) X-rays are used for research purposes. They are widely used in x-ray photographing.

iv) Some types of bacteria and viruses are killed by irradiation. If a solution of viruses is irradiated, they are unable to reproduce.

v) Carbon dating is the most common way to determine the age of ancient remains by measuring the radioactive level of the ^{14}C.

Appendix1

Example of nuclear data tables:

Iron Nuclear Data

Z	A	Atomic Mass (u)	Nuclear Mass(GeV/c2	Binding Energy(MeV)	Spin	Natural Abund.	Half-life	Decay	Q MeV
26	54	53.939613	50.2315	471.77	0	0.059	stable	...	...
26	55	54.938296	51.1618	481.07	3/2	...	2.7y	EC	0.23
26	56	55.934939	52.0902	492.26	0	0.9172	stable	...	...
26	57	56.935396	53.0221	499.91	1/2	0.021	stable	...	...
26	58	57.933277	53.9517	509.96	0	0.0028	stable	...	...
26	60	59.934077	55.8154	525.35	0	...	1.5My	b-	0.24

The isotope ^{56}Fe is the most abundant of the heavy elements. Near the top of the binding energy curve, it is exceeded in binding energy only by ^{62}Ni and ^{58}Fe.

Cobalt Nuclear Data

Z	A	Atomic Mass (u)	Nuclear Mass(GeV/c2	Binding Energy(MeV)	Spin	Natural Abund.	Half-life	Decay	Q MeV
27	56	55.939841	52.0943	486.92	4	...	77.7d	b+	4.57
27	57	56.936294	53.0225	498.29	7/2	...	271d	EC	0.84
27	59	58.933198	54.8826	517.32	7/2	1.00	stable	...	...
27	60	59.933820	55.8147	524.81	5	...	5.272y	b-	2.82